CAPE CANAVERAL AIR FORCE STATION, LAUNCH COMPLEX 39, CRAWLER TRANSPORTERS
(John F. Kennedy Space Center)
Launcher Road, East of Kennedy Parkway North
Cape Canaveral
Brevard County
Florida

HAER FL-8-11-C
FL-8-11-C

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
SOUTHEAST REGIONAL OFFICE
National Park Service
U.S. Department of the Interior
100 Alabama St. NW
Atlanta, GA 30303

HISTORIC AMERICAN ENGINEERING RECORD

CAPE CANAVERAL AIR FORCE STATION, LAUNCH COMPLEX 39, CRAWLER TRANSPORTERS (John F. Kennedy Space Center)

HAER No. FL-8-11-C

Location:	Launcher Road, east of Kennedy Parkway North John F. Kennedy Space Center Cape Canaveral Brevard County Florida U.S.G.S. 7.5. minute Orsino, Florida, quadrangle, Universal Transverse Mercator coordinates (Parking/Maintenance site): 17.533724.3162403
Date of Construction:	1964-1966
Architect:	Marion Power Shovel Company, Ohio
Builder:	Marion Power Shovel Company, Ohio (at KSC)
Present Owner:	National Aeronautics and Space Administration (NASA) Kennedy Space Center, FL 32899-0001
Present Use:	Aerospace Facility-vehicle transportation
Significance:	The Crawler Transporters (Crawlers) were listed in the National Register of Historic Places (NRHP) on January 21, 2000. Originally nominated in the context of the Apollo Program, ca. 1961 through 1975, the Crawlers have since gained importance in the context of the Space Shuttle Program, ca. 1969 to 2010. They are significant at the national level under NRHP Criterion A in the areas of Transportation and Space Exploration, and under Criterion C in the area of Engineering. Because the Crawlers have achieved significance within the past fifty years, Criteria Consideration G applies. The Crawlers are unique and are used only as transporters for space vehicles. They have provided continuous service to the nation's space programs since the 1960s, and today play a vital role in the Space Shuttle Program by moving the Shuttle to the pad in preparation for launch. Under Criterion C, the Crawlers were constructed specifically for the task of transporting assembled space flight vehicles from the Vehicle Assembly Building (VAB) to the launch pad. As such, each Crawler was designed to carry a weight of over twelve million pounds, exclusive of its own weight of six million pounds. In addition, the vehicles are equipped

with a leveling system to keep the Shuttle vertical during the trip to the launch pad.

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Date: September 2009

HISTORICAL INFORMATION

NASA's John F. Kennedy Space Center

The John F. Kennedy Space Center (KSC) is the National Aeronautics and Space Administration's (NASA) primary Center for launch and landing operations, vehicle processing and assembly, and related programs in support of manned space missions. It is located on the east coast of Florida, about 150 miles south of Jacksonville, and to the north and west of Cape Canaveral, in Brevard and Volusia Counties, and encompasses almost 140,000 acres. The Atlantic Ocean and Cape Canaveral Air Force Station (CCAFS) are located to the east, and the Indian River is to the west.

Following the launch of Sputnik I and Sputnik II, which placed Soviet satellites into Earth's orbit in 1957, the attention of the American public turned to space exploration. President Dwight D. Eisenhower initially assigned responsibility for the U.S. Space Program to the Department of Defense (DoD). The Development Operations Division of the Army Ballistic Missile Agency (ABMA), led by Dr. Wernher von Braun, began to focus on the use of missiles to propel payloads, or even a man, into space. The United States successfully entered the space race with the launch of the Army's scientific satellite Explorer I on January 31, 1958 using a modified Jupiter missile named Juno I.[1]

With the realization that the military's involvement in the space program could jeopardize the use of space for peaceful purposes, President Eisenhower established NASA on October 1, 1958 as a civilian agency with the mission of carrying out scientific aeronautical and space exploration, both manned and unmanned. Initially working with NASA as part of a cooperative agreement, President Eisenhower officially transferred to NASA a large portion of the Army's Development Operations Division, including the group of scientists led by von Braun, and the Saturn rocket program.[2]

NASA became a resident of Cape Canaveral in 1958 when the Army Missile Firing Laboratory (MFL), then working on the Saturn rocket project under the direction of Kurt Debus, was transferred to the agency. Several Army facilities at CCAFS were given to NASA, including various offices and hangars, as well as Launch Complexes (LC) 5, 6, 26, and 34. The MFL was renamed Launch Operations Directorate (LOD) and became a branch office of Marshall Space Flight Center (MSFC). As LOD responsibilities grew, NASA granted the launch team increased status by making it a field center called the Launch Operations Center (LOC), and separating it from MSFC.

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[1] Charles D. Benson and William B. Faherty. *Gateway to the Moon. Building the Kennedy Space Center Launch Complex*. (Gainesville, University Press of Florida, 2001), 1-2.
[2] Benson and Faherty, *Gateway*, 15.

In May 1961, President John F. Kennedy charged NASA and the associated industries to develop a space program that would surpass the Soviet program by landing a man on the Moon by the end of the decade. With the new, more powerful Saturn V rocket and the stepped-up launch schedule, it was apparent that a new launch complex was required, and CCAFS, with twenty-two launch complexes, did not have the space for new rocket facilities. Merritt Island, an undeveloped area west and north of the Cape, was selected for acquisition, and in 1961 the Merritt Island Launch Area (MILA, which, with the LOC, would become KSC) was born. In that year, NASA requested from Congress authority to purchase 80,000 acres of property, which was formally granted in 1962. The U.S. Army Corps of Engineers (ACOE) acted as agent for purchasing the land, which took place between 1962 and 1964. NASA began gaining title to the land in late 1962, taking over 83,903.9 acres by outright purchase, which included several small towns, such as Orsino, Wilson, Heath and Audubon, many farms, citrus groves, and several fish camps. Negotiations with the State of Florida provided submerged lands, resulting in the acquisition of property identified on the original Deed of Dedication. Much of the State-provided land was located south of the Old Haulover Canal and north of the Barge Canal.

The American program to put a man in space and land on the Moon proceeded rapidly with widespread support. In November 1963, the LOC and MILA were renamed John F. Kennedy Space Center to honor the late President.[3] The space program was organized into three phases: Projects Mercury, Gemini, and Apollo. Project Mercury, initiated in 1958, was executed in less than five years. Begun in 1964, Project Gemini was the intermediate step toward achieving a manned lunar landing, bridging the gap between the short-duration Mercury flights and the long-duration missions proposed for the Apollo Program.[4]

Apollo, the largest and most ambitious of the manned space programs, had as its goal the landing of astronauts on the Moon and their safe return to Earth. Providing the muscle to launch the spacecraft was the Saturn family of heavy vehicles. Saturn IB rockets were used to launch the early unmanned Apollo test flights and the first manned flight, Apollo 7, which carried astronauts on a ten-day earth orbital mission.[5]

Three different launch vehicles were used in Apollo: Saturn I, Saturn IB and Saturn V; and three different launch complexes were involved: LC 34 and LC 37 on CCAFS, and LC 39 on KSC (only LC 39 is still active). Altogether, thirty-two Saturn flights occurred (seven from LC 34, eight from LC 37, and seventeen from LC 39, including Skylab and the Apollo-Soyuz Test Project) during the Apollo era. Of the total thirty-two, fifteen were manned, and of the seven attempted lunar landing missions, six were successful. No major launch vehicle failures of either

[3] Harry A Butowsky. *Reconnaissance Survey: Man in Space*. (Washington, D.C.: National Park Service, 1981), 5; Benson and Faherty, *Gateway*, 146.
[4] Butowsky, 5.
[5] Butowsky, 5.

Saturn IB or Saturn V occurred. There were two major command/service module (CSM) failures, one on the ground (Apollo 1) and one on the way to the Moon (Apollo 13).[6]

The unmanned Apollo 4 mission, which lifted off on November 9, 1967, was the first Saturn V launch and the first launch from LC 39 at KSC. On July 21, 1969, the goal of landing a man on the Moon was achieved when Apollo 11 astronauts Armstrong, Aldrin, and Collins successfully executed history's first lunar landing. Armstrong and Aldrin walked on the surface of the Moon for twenty-two hours and collected 21 kilograms of lunar material. Apollo 17 served as the first night launch in December 1972. An estimated 500,000 people saw the liftoff, which was the final launch of the Apollo Program.[7]

Skylab, an application of the Apollo Program, served as an early type of space station. With 12,700 cubic feet of work and living space, it was the largest habitable structure ever placed in orbit, at the time. The station achieved several objectives: scientific investigations in Earth orbit (astronomical, space physics, and biological experiments); applications in Earth orbit (earth resources surveys); and long-duration spaceflight. Skylab 1 orbital workshop was inhabited in succession by three crews launched in modified Apollo CSMs (Skylab 2, 3 and 4). Actively used until February 1974, Skylab 1 remained in orbit until July 11, 1979, when it re-entered Earth's atmosphere over the Indian Ocean and Western Australia after completing 34,181 orbits.[8]

The Apollo-Soyuz Test Project (ASTP) of July 1975, the final application of the Apollo Program, marked the first international rendezvous and docking in space, and was the first major cooperation between the only two nations engaged in manned space flight. As the first meeting of two manned spacecraft of different nations in space, first docking, and first visits by astronauts and cosmonauts into the others' spacecraft, the ASTP was highly significant. The ASTP established workable joint docking mechanisms, taking the first steps toward mutual rescue capability of both Russian and American manned missions in space.[9]

On January 5, 1972, President Nixon delivered a speech in which he outlined the end of the Apollo era and the future of a reusable space flight vehicle, the Space Shuttle, which would provide "routine access to space." By commencing work at this time, Nixon added, "we can have the Shuttle in manned flight by 1978, and operational a short time after that".[10] The Space Task Group (STG), previously established by President Nixon in February 1969 to recommend a future course for the U.S. Space Program, presented three choices of long-range space plans. All included an Earth–orbiting space station, a space shuttle, and a manned Mars expedition.[11]

[6] NASA. *Facts: John F. Kennedy Space Center.* (1994), 82.
[7] NASA. *Facts*, 86-90.
[8] NASA. *Facts*, 91.
[9] NASA. *Facts*, 96.
[10] Marcus Lindroos. "President Nixon's 1972 Announcement on the Space Shuttle." (NASA Office of Policy and Plans, NASA History Office, updated 14 April 2000).
[11] NASA, History Office, NASA Headquarters. "Report of the Space Task Group, 1969."

Although none of the original programs presented was eventually selected, NASA implemented a program, shaped by the politics and economic realities of its time that served as a first step toward any future plans for implementing a space station.[12]

During this speech, President Nixon instructed NASA to proceed with the design and building of a partially reusable space shuttle consisting of a reusable orbiter, three reusable main engines, two reusable solid rocket boosters (SRBs), and one non-reusable external liquid fuel tank (ET). NASA's administrators vowed that the shuttle would fly at least fifty times a year, making space travel economical and safe. NASA gave responsibility for developing the shuttle orbiter vehicle and overall management of the Space Shuttle Program (SSP) to the Manned Spacecraft Center (MSC; now Johnson Space Center [JSC]) in Houston, based on the Center's experience. MSFC in Huntsville, Alabama was responsible for development of the Space Shuttle Main Engine (SSME), the SRBs, the ET, and for all propulsion-related tasks. Engineering design support continued at MSC, MSFC and NASA's Langley Research Center (LaRC), in Virginia, and engine tests were to be performed at NASA's National Space Technology Laboratories (NSTL, later named Stennis Space Center [SSC]) in Mississippi, and at the Air Force's Rocket Propulsion Laboratory in California, which later became the Santa Susana Field Laboratory (SSFL).[13] NASA selected KSC as the primary launch and landing site for the SSP. KSC, responsible for designing the launch and recovery facilities, was to develop methods for shuttle assembly, checkout, and launch operations.[14]

On September 17, 1976, the full-scale Orbiter Vehicle (OV) prototype *Enterprise* (OV- 101) was completed. Designed for test purposes only and never intended for space flight, structural assembly of this orbiter had started more than two years earlier in June 1974 at Air Force Plant (AFP) 42 in Palmdale, California. Although the *Enterprise* was an aluminum shell prototype incapable of space flight, it reflected the overall design of the orbiter. As such, it served successfully in 1977 as the test article during the Approach and Landing Tests (ALT) aimed at checking out both the mating with the Boeing 747 Shuttle Carrier Aircraft (SCA) for ferry operations, as well as the orbiter's unpowered landing capabilities.

The first orbiter intended for space flight, *Columbia* (OV-102), arrived at KSC from AFP 42 in March 1979. Originally scheduled to lift off in late 1979, the launch date was delayed by problems with both the SSME components as well as the thermal protection system (TPS). *Columbia* spent 610 days in the Orbiter Processing Facility (OPF), another thirty-five days in the

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[12] Dennis R. Jenkins. *Space Shuttle, The History of the National Space Transportation System. The First 100 Missions*. (Cape Canaveral, Florida: Specialty Press, 2001), 99.
[13] Jenkins, 122.
[14] Linda Neuman Ezell. *NASA Historical Databook Volume III Programs and Projects 1969-1978*. The NASA History Series, NASA SP-4012, (Washington, D.C.: NASA History Office, 1988), Table 2-57; Ray A. Williamson. "Developing the Space Shuttle." *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume IV: Accessing Space*. (Edited by John M. Logsdon. Washington, D.C.: U.S. Printing Office, 1999), 172-174.

Vehicle Assembly Building (VAB) and 105 days on Launch Pad 39A before finally lifting off on April 12, 1981. STS-1, the first orbital test flight and first Space Shuttle Program mission, ended with a landing on April 14 at Edwards Air Force Base (AFB) in California. This launch demonstrated *Columbia's* ability to fly into orbit, conduct on-orbit operations, and return safely.[15] *Columbia* flew three additional test flights in 1981 and 1982, all with a crew of two. The Orbital Test Flight Program ended in July 1982 with 95 percent of its objectives completed. After the end of the fourth mission, President Ronald Reagan declared that with the next flight the Shuttle would be "fully operational."

A total of 125 Space Shuttle missions have been launched from the KSC between April 1981 and March 2009. From April 1981 until the *Challenger* accident in January 1986, between two and nine missions were flown yearly, with an average of four to five per year. The milestone year was 1985, when nine flights were successfully completed. The years between 1992 and 1997 were the most productive, with seven or eight yearly missions. Since 1995, in addition to its unique responsibility as the shuttle launch site, KSC also became the preferred landing site.

Over the past two decades, the SSP has launched a number of planetary and astronomy missions including the Hubble Space Telescope (HST), the Galileo probe to Jupiter, Magellan to Venus, and the Upper Atmospheric Research Satellite. In addition to astronomy and military satellites, a series of Spacelab research missions were flown, which carried dozens of international experiments in disciplines ranging from materials science to plant biology. Spacelab was a manned, reusable, microgravity laboratory flown into space in the rear of the Space Shuttle cargo bay. It was developed on a modular basis allowing assembly in a dozen arrangements depending on the specific mission requirements.[16] The first Spacelab mission, carried aboard *Columbia* (STS-9), began on November 28, 1983. Four Spacelab missions were flown between 1983 and 1985. Following a hiatus in the aftermath of the *Challenger* disaster, the next Spacelab mission was not launched until 1990. In total, twenty-four Space Shuttle missions carried Spacelab hardware before the program was decommissioned in 1998.[17] In addition to astronomical, atmospheric, microgravity, and life sciences missions, Spacelab was also used as a supply carrier to the HST and the Soviet space station *Mir*.

In 1995, a joint U.S./Russian Shuttle-*Mir* Program was initiated as a precursor to construction of the International Space Station (ISS). *Mir* was launched in February 1986 and remained in orbit until March 2001.[18] The first approach and flyaround of *Mir* took place on February 3, 1995 (STS-63); the first *Mir* docking was in June 1995 (STS-71). During the three-year Shuttle-*Mir*

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[15] Jenkins, 268.
[16] NASA. *NASA Shuttle Reference Manual.* (1988).
[17] STS-90, which landed on 3 May 1998, was the final Spacelab mission. NASA KSC. "Shuttle Payloads and Related Information." KSC Factoids. Revised 18 November 2002.
[18] Tony Reichhardt (editor). *Space Shuttle, The First 20 Years.* (Washington, D.C.: Smithsonian Institution, 2002), 85.

Program (June 27, 1995 to June 2, 1998) the Space Shuttle docked with *Mir* nine times. All but the last two of these docking missions used the Orbiter *Atlantis*. In 1995, Dr. Norman Thagard was the first American to live aboard the Russian space station. Over the next three years, six more U.S. astronauts served tours on *Mir*. The Shuttle served as a means of transporting supplies, equipment and water to the space station in addition to performing a variety of other mission tasks, many of which involved earth science experiments. It returned to Earth experiment results and unneeded equipment. The Shuttle-*Mir* program served to acclimate the astronauts to living and working in space. Many of the activities carried out were types they would perform on the ISS.[19]

On December 4, 1999, *Endeavour* (STS-88) launched the first component of the ISS into orbit. As noted by Williamson, this event marked, "at long last the start of the Shuttle's use for which it was primarily designed – transport to and from a permanently inhabited orbital space station."[20] STS-96, launched on May 27, 1999, marked the first mission to dock with the ISS. Since that time, most Space Shuttle missions have supported the continued assembly of the space station. As currently planned, ISS assembly missions will continue through the life of the Space Shuttle Program.

The SSP suffered two major setbacks with the tragic losses of the *Challenger* and *Columbia* on January 28, 1986 and February 1, 2003, respectively. Following the *Challenger* accident, the SSP was suspended, and President Ronald Reagan formed a thirteen-member commission to identify the cause of the disaster. The Rogers Commission report, issued on June 6, 1986, which also included a review of the SSP, concluded "that the drive to declare the Shuttle operational had put enormous pressures on the system and stretched its resources to the limit".[21] In addition to mechanical failure, the Commission noted a number of NASA management failures that contributed to the catastrophe. As a result, among the tangible actions taken were extensive redesign of the SRBs; upgrading of the Space Shuttle tires, brakes, and nose wheel steering mechanisms; the addition of a drag chute to help reduce speed upon landing; the addition of a crew escape system; and the requirement for astronauts to wear pressurized flight safety suits during launch and landing operations. Other changes involved reorganization and decentralization of the SSP. NASA moved the management of the program from JSC to NASA Headquarters, with the aim of preventing communication deficiencies.[22] Experienced astronauts were placed in key NASA management positions, all documented waivers to existing flight safety criteria were revoked and forbidden, and a policy of open reviews was implemented.[23] In addition, NASA adopted a Space Shuttle flight schedule with a reduced average number of launches, and discontinued the long-term practice of launching commercial and military

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[19] Judy A. Rumerman, with Stephen J. Garber. *Chronology of Space Shuttle Flights 1981-2000*. HHR-70. (Washington, D.C.: NASA History Division, Office of Policy and Plans, October 2000), 3.
[20] Williamson, 191.
[21] Columbia Accident Investigation Board (CAIB). *Report Volume I*. (August 2003), 25.
[22] CAIB, 101.
[23] Cliff Lethbridge. "History of the Space Shuttle Program." (2001), 4.

payloads.[24] The launch of *Discovery* (STS-26) from KSC Pad 39B on September 29, 1988 marked a Return to Flight after a thirty-two-month hiatus in manned spaceflight following the *Challenger* accident.

In the aftermath of the 2003 *Columbia* accident, a seven month investigation ensued, concluding with the findings of the Columbia Accident Investigation Board (CAIB), which determined that both technical and management conditions accounted for the loss of the orbiter and crew. According to the CAIB Report, the physical cause of the accident was a breach in the TPS on the leading edge of the left wing, caused by a piece of insulating foam, which separated from the ET after launch and struck the wing.[25] NASA spent more than two years researching and implementing safety improvements for the orbiters, SRBs and ET. Following a two-year hiatus, the launch of STS-114 on July 26, 2005 marked the first Return to Flight since the loss of *Columbia.*

On January 14, 2004, President George W. Bush outlined a new space exploration initiative in a speech given at NASA Headquarters.

> *Today I announce a new plan to explore space and extend a human presence across our solar system . . . Our first goal is to complete the International Space Station by 2010 . . . The Shuttle's chief purpose over the next several years will be to help finish assembly of the International Space Station. In 2010, the Space Shuttle – after nearly 30 years of duty – will be retired from service. . . Our second goal is to develop and test a new spacecraft, the Crew Exploration Vehicle, by 2008, and to conduct the first manned mission no later than 2014. . . Our third goal is to return to the Moon by 2020, as the launching point for missions beyond ...*[26]

Following the President's speech, NASA released *The Vision for Space Exploration*, which outlined the Agency's approach to the new direction in space exploration.[27] In 2006, NASA announced the start of the Constellation Program, which included development of the Crew Exploration Vehicle (CEV) and a launch vehicle to place the CEV into space. As part of this initiative, NASA will continue to use the Space Shuttle to complete assembly of the ISS. The Shuttle will not be upgraded to serve beyond 2010 and, after completing the ISS, the Space Shuttle Program will be retired. The next generation of human-rated spacecraft, the CEV, named *Orion*, will transport humans to low Earth orbit for missions to support the ISS, and will also be the vehicle used to carry a crew to lunar orbit. The Constellation Program will develop the new

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[24] Lethbridge, 5.
[25] CAIB, 9.
[26] The White House. "A Renewed Spirit of Discovery – The President's Vision for Space Exploration." (January 2004).
[27] NASA Headquarters. "The Vision for Space Exploration." (February 2004).

class of exploration vehicles to launch both crew and cargo and associated infrastructure in exploring the Moon, Mars, and beyond.

Development of KSC's LC 39 and VAB Areas

Today, KSC maintains operational control over 3,800 acres, all located in Brevard County. The major facilities are located within the Industrial Area, the LC 39 Area, the VAB Area, and the Shuttle Landing Facility (SLF) Area. The LC 39 and VAB Areas were developed primarily to support launch vehicle operations and related launch processing activities. They contain the VAB, the Launch Control Center (LCC), the Orbiter Processing Facilities (OPF), the two Launch Pads, A and B, and other support facilities.

Following completion of the Apollo-Soyuz Test Project in 1975, the facilities of KSC were modified to support the Space Shuttle Program. KSC was originally one of three possible launch sites evaluated, along with Vandenberg AFB in California and the White Sands Missile Range in New Mexico. Compared with the other two locations, KSC had the advantage of approximately $1 billion in existing launch facilities. Thus, less time and money would be needed to modify existing facilities at KSC rather than to build new ones at another location. The estimate of $200 to $400 million to modify the existing KSC facilities was roughly half the cost of new construction. In addition, only KSC had abort options for a first revolution return of the low cross-range orbiter.[28]

To help keep costs down, beginning ca. 1976, KSC engineers adapted and modified many of the Apollo launch facilities to serve the needs of the SSP. Among the key facilities undergoing change were the VAB, the LCC, and LC 39 Pads A and B. New facilities were constructed only when a unique requirement existed. The major new structures included the SLF and the OPFs. Multi-million dollar contracts for design and construction were awarded to both national and local firms, including Reynolds, Smith and Hills (RS&H) of Jacksonville, Florida; the Frank Briscoe Company, Inc. of East Orange, New Jersey; Algernon Blair Industrial Contractors, Inc. of Norcross, Georgia; the Holloway Corporation of Titusville, Florida; and W&J Construction Corporation of Cocoa, Florida.

Alterations to the VAB included modification of two of the four high bays for assembly of the Space Shuttle vehicle, and changes to the other two high bays to accommodate the processing and stacking of the SRBs and ET. The north doors were widened by almost 40' to permit entry of the towed orbiter. Work platforms shaped to fit the shuttle configuration were added to High Bays 1 and 3 where shuttle assembly takes place, and internal structural changes were also made to High Bays 2 and 4, where the ETs are processed.

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[28] Jenkins, 112.

Major changes were made to LC 39, Pads A and B. Modifications were completed in mid-1978 at Pad A and in 1985 at Pad B. With the exception of the six fixed pedestals which support the Mobile Launcher Platform (MLP), all of the structures on the hardstands of each pad were removed or relocated. Fuel, oxidizer, high-pressure gas, electrical, and other service lines were rerouted. New hypergolic fuel and oxidizer support areas were constructed at the southwest and southeast corners, respectively, of the pads; the unneeded Saturn fuel support area was removed, a new Fixed Service Structure (FSS) was erected using an original Apollo-era Launch Umbilical Tower (LUT), a Rotating Service Structure (RSS) was added, the Saturn flame deflectors were replaced, and a Payload Changeout Room (PCR) and Payload Ground Handling Mechanism (PGHM) were added. A sound suppression water system was installed on the pads to reduce the acoustical levels within the orbiter's payload and thus, to protect it and its payloads from damage. A related system, the Overpressure Suppression System, was installed to reduce the pressure pulse at SRB ignition.[29]

Additional changes were made to Pad A and Pad B in the aftermath of the 1986 *Challenger* accident; other modifications followed the Return to Flight in 1988. Among the modifications were the installation of new weather protection structures to supplement the RSS; improvements in temperature and humidity controls for the PCR; upgrades to the emergency exit system, including the addition of two slidewire baskets; installation of new elevators on the RSS; and improvements to the pad communications system. Changes were first made at Pad B, followed by identical changes at Pad A.

The Crawler Transporters

As previously discussed, the Apollo Program, which was set to use the powerful Saturn V rocket, required a new launch complex; thus LC 39 at KSC was conceived.[30] The tremendously large and complex rocket also prompted research into new methods of preparing the vehicle for its voyage into space. Up to this point, all rockets and space modules had been prepared at the launch pad, but they were much simpler in configuration, relying on a single booster to reach orbit as opposed to the planned two or three booster stages for the Apollo vehicles. Additionally, this new configuration would require a lengthened processing time, presenting a greater potential for delays in processing and check-out due to inclement weather, especially if these activities were completed at the launch pad. Therefore, the decision was made to construct an enclosed facility for vehicle processing, assembly, and check-out (the VAB); and then transport the vehicle atop its launch platform to the launch pad.[31]

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[29] Wallace H. Boggs and Samuel T. Beddingfield. "Moonport to Spaceport. The Changing Face at KSC." *Astronautics & Aeronautics,* July-August 1982, 28-41.
[30] See page 4.
[31] Benson and Faherty, *Gateway*, 112-116; American Society of Mechanical Engineers (ASME). *National Historic Mechanical Engineering Landmark: Crawler Transporters of Launch Complex 39, Kennedy Space Center.* ASME,

The next piece of the puzzle was to determine that means of transportation. Regardless of the method, the transporter had to be capable of moving a twelve million pound vehicle/launcher combination for either 3.5 or 5 miles (the distance from the VAB to Pad A and B, respectively), while maintaining the vehicle in a vertical orientation through potential winds of 52 miles per hour. The first studies for LC 39 (1961) by Martin Marietta Corporation focused on using either a barge and canal system or a rail line to transport the Apollo vehicle to the launch pad. The initial cost estimates favored the barge system, but further inquiries (late 1961/early 1962) raised substantial questions as to its propulsion and steering capabilities, as well as its ability to keep the vehicle stable. Concurrent with these studies was a comprehensive survey by American Machine and Foundry Company, which examined various methods of hauling the vehicle, including a barge and canal system, railway wheels, pneumatic tires, and crawler treads; this study resulted in the suggestion of a combined barge and rail system.[32]

In the midst of these studies, a visitor was received by O.K. Duren, Deputy Chief of the Future Launch Systems Study Office at MSFC. The caller was Barry Schlenk, a representative of the Bucyrus-Erie Company (BEC), of Milwaukee, Wisconsin. He had heard about the vehicle transport conundrum, and with him, brought pictures of a steam-shovel crawler designed and built by his company for use in the coal fields of Kentucky. This meeting set in motion a series of phone calls between NASA personnel, which led to an on-site visit at the coal mine in February 1962. The following month, NASA hired BEC to study the use of a crawler-style vehicle to transport the Saturn rocket. At first, BEC's studies focused on a combination crawler/mobile launcher. As their research continued, they discovered that it would be cheaper to separate the two components. In April 1962, they suggested this design to NASA officials, who authorized BEC to continue their work, but focus on studying the "Crawler" as a separate entity. The results were successful, and at a conference over June 12 and 13, 1962, NASA formally decided to proceed with the use of a crawler transporter.[33]

Since BEC had completed the initial studies and was the only company in the U.S. who had built anything like the Crawlers, many assumed they would get the design/build contract. However, KSC opened the door for competitive bidding, holding a pre-proposal meeting for interested parties in December 1962. Of the twenty-two firms who attended the conference, only two submitted bids: BEC at $11 million and Marion Power Shovel Company (MPSC) of Marion,

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3 February 1977, 6; "Ohio Firm Will Build Cape Canaveral Vehicle." *Space News Roundup* (2, 9) 20 February 1963: 8.

[32] Benson and Faherty, *Gateway*, 116-122; ASME, 6; NASA KSC. *Kennedy Space Center Story*. (KSC), 1972, 29.

[33] Benson and Faherty, *Gateway*, 118, 120-122; "Saturn C-5 Will Crawl To Pad for Space Trip." *Marshall Star* (2, 43) 25 July 1962: 1; NASA KSC. *Building KSC's Launch Complex 39*. NASA Facts FS-2002-08-010-KSC, (KSC), October 2002, rev. 2006; NASA KSC. *KSC Transporters*. NASA Facts FS-2000-04-28-KSC (KSC), April 2000.

Ohio, at $8 million. As the low bidder, the contract was awarded to MPSC in February 1963. In an ironic twist, they hired Philip Koehring of BEC to serve as project manager for the job.[34]

MPSC planned to build the major components in their Ohio plant, then take them apart and ship the pieces by rail to KSC, where they would complete the final assembly. By December 1963, MPSC completed 90 percent of the design work; they promised to deliver the first components to KSC in March 1964.[35] However, their progress wavered in December 1963, when American Machine and Foundry Company, whom MPSC had hired as the subcontractor for the steering and leveling hydraulic system, found that the initial designs for this system were "too quick and sensitive in their actions." A third-party review by two other companies, Bendix Corporation and General Electric, confirmed the findings; therefore, changes had to be made to the original design.[36]

Between design issues and labor disputes, the first Crawler finally moved under its own power on January 23, 1965; however, NASA personnel noted many problems that needed to be resolved. In April, further runs of the Crawler were conducted, which included the first tests of the propulsion and steering systems. Subsequently, in June, the hydraulic jack and leveling system was tested for the first time, with the load being one of the mobile launchers. Although the test was considered successful, NASA personnel noted high hydraulic pressures at turns. In addition, the Crawler destroyed the macadam surface of the road, leading to a reevaluation of the "Crawlerway."[37]

On July 24, 1965, the Crawler was driven for approximately one mile over two different road surfaces, washed gravel ("Alabama River Rock") and crushed granite, to gather comparative data. Over the next few days after the tests, pieces of bronze and steel were found throughout the roadway; a follow-up look at the Crawler revealed that fourteen of its 176 tapered roller bearings were damaged. This exposed two additional design flaws; first, the amount of friction was underestimated, and second, it was assumed there would always be an equal load distribution over the rollers, which proved to be false. With the help of MSFC, a new sleeve bearing was developed, and the Crawler design was reworked so that there were separate bearings for axial thrust and radial loads. Although this did not reduce friction, it did eliminate the possibility of a sudden failure. The friction problem was overcome by doubling the operating pressure of the steering hydraulic system. On January 28, 1966, Crawler Transporter No. 1 (CT-1) carried one of the mobile launchers to the VAB, a distance of one mile, with no major malfunctions. On May 25, 1966, CT-1 carried the Apollo-Saturn 500-F test vehicle to the launch pad for verification,

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[34] Benson and Faherty, *Gateway*, 272; NASA KSC, "KSC Story," 29; "Advanced Saturn Transport Mode Proposal Sought." *Marshall Star* (3, 14) 2 January 1963: 1; "Ohio Firm," 8.

[35] Charles D. Benson and William B. Faherty, *Moon Launch! A History of the Saturn-Apollo Launch Operations.* Gainesville, University Press of Florida, 2001, 326; "Ohio Firm," 8.

[36] Benson and Faherty, *Gateway*, 273.

[37] Benson and Faherty, *Moon Launch!*, 326; NASA KSC. *Crawler Transporters.* NASA Facts FS-2006-01-001-KSC (KSC), January 2006.

training, and procedural development. The second Crawler (Crawler Transporter No. 2; CT-2), which incorporated various changes due from the testing of CT-1, was formally accepted by KSC in September 1966.[38]

The unmanned Apollo 4 mission, launched in November 1967, was the first to liftoff from LC 39, and thus was the first fueled rocket to be transported by a Crawler.[39] Over their first ten years of existence (1966-76), the two transporters served seventeen missions (twelve for the Apollo program; four for the Skylab program; and one for the Apollo-Soyuz program). In 1969, England's Royal Automobile Club awarded the Crawlers their Diamond Jubilee Trophy. This trophy is "[a]warded to an individual, group of individuals, or corporation of any nationality, for an outstanding contribution in the field of automotive transport. The Trophy was instituted to commemorate the Diamond Jubilee of the Club in 1957."[40]

In early 1974, the decision was made to use the Crawlers to transport the new Space Shuttle vehicle to the launch pad. Although they had undergone a few alterations up to that point, a "state of the art refurbishment" was planned for each.[41] This included the replacement of all outdated electronic components; a new central control room with a programmable controller; and upgrades to both the steering electronics system and the jacking, equalization, and leveling (JEL) system. This work was scheduled to be completed by December 1978 for CT-1 and by the end of 1979 for CT-2.[42] The first assignment of the new program was to transport the *Enterprise*, mated to an inert ET and SRBs, to the launch pad for fit checks.[43]

On February 3, 1977, the American Society of Mechanical Engineers (ASME) designated the Crawlers as a National Historic Mechanical Engineering Landmark. They were the eighteenth landmark to be given this designation since the program's beginning in 1973. According to the event's brochure, the program "is to promote a general awareness of our technological heritage among both engineers and the general public. A charge given to the Committee is to gather data on all works and artifacts with a mechanical engineering connection which are historically significant to the profession." At the time, they were the largest ground vehicles ever built.[44]

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[38] Benson and Faherty, *Moon Launch!*, 327-328; "Saturn V Crawler's New Bearings Tested at MSFC." *Marshall Star* (6, 5) October 20 1965: 7; "Saturn V Test Vehicle Moves to Launch Pad." *Space News Roundup* (5, 16) 27 May 1966: 8; "Second Transporter 'Accepted'." *Spaceport News* (5, 33), 29 September 1966: 8.
[39] NASA KSC, *Crawler Transporters*.
[40] The Trophy is awarded on the recommendation of the Club's Technical Committee and is held for one calendar year. Trevor Dunmore. Personal communication with Patricia Slovinac, 3 March 2009.
[41] "Transporters Will Play Major Role in Space Shuttle Program." *Spaceport News* (13, 6), 21 March 1974: 5.
[42] "Transporters Will Play Major Role;" Frank E. Jarrett. "Chronology of KSC and KSC Related Events for 1977." KHR-3, 1 November 1978, 76; Kyle Herring. "Transporter crosses 1,000 mile marker." *Spaceport News* (29, 17), 27 April 1990, 4.
[43] Frank E. Jarrett. "Chronology of KSC and KSC Related Events for 1979." KHR-4, 22 September 1980, 32.
[44] "Advanced Saturn Transport Mode Proposal Sought." *Marshall Star* (3, 14) 2 January 1963: 1; ASME; NASA KSC, *Crawler Transporters*. NASA Facts FS-2006-01-001-KSC (KCS), January 2006. In 1978, the Crawlers were

Since the start of the Space Shuttle Program, the Crawlers have undergone a few additional modifications. In 1982, due to repeated leaks and failures, both of the main and redundant superchargers in each Crawler were replaced.[45] In 1985 a laser docking system was added, allowing the Crawlers to dock within 0.50 to 0.25 inches of the fixed "dead zero" position at the launch pad. In 2003, an inspection of the Crawlers revealed fatigue cracks in several track shoes; therefore each transporter received a complete new set of shoes (456 per vehicle), which were made by ME Global Manufacturing in Duluth, Minnesota. Around the same time, each Crawler received a new muffler, and a new air conditioning and ventilation system; the most visible element of this alteration was the three large exhaust pipes on each end. Around 2004, the two controller's cabs on both transporters were refitted with hurricane-rated glass; the consoles that dated to the Shuttle program refurbishment remained. In 2007, all of the catwalks around the vehicle were replaced, although they were modeled on the originals; and in 2008, extensions were added to the guard rails as an additional safety measure.[46]

Crawler Transporter Functions

The Crawler Transporters were originally used in support of the Apollo Program. Their job was to transport the mobile launcher (ML) to the VAB for vehicle assembly, and then carry the Apollo vehicle and ML combination to the launch pad. At the pad, the Crawlers were also used to transfer the Mobile Service Structure (MSS), which was used for vehicle processing, from its park site to the pad. The Crawlers have provided similar support for the Space Shuttle Program. They carry the mobile launcher platform (MLP) into the VAB for vehicle assembly; transport the fully assembled Space Shuttle vehicle and MLP combination from the VAB to the launch pad; and return the MLP to its parking/maintenance site following the launch.[47]

When a Crawler is not in use, it is generally stored at its maintenance and parking site to the northwest of the VAB. Here, the vehicle is taken care of by the Crawler Transporter Group division of United Space Alliance. This group performs preventative and corrective maintenance; troubleshoots any problems; completes modifications and refurbishments; and conducts pre-operational set-ups, operational support, and post operational testing.[48] In addition, the group administers an examination of all systems within the Crawler, replaces any electrical/mechanical components (such as circuit breakers), repairs or replaces any engine component, and thoroughly

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superseded in size by the Bagger 288, a bucket-wheel excavator constructed by the German company, Krupp. "Bagger 288." *Wikipedia*. Last modified, 18 December 2008. http://en.wikipedia.org/wiki/Bagger_288.

[45] Raymond Trapp. Interview with Patricia Slovinac, KSC, Crawler Transporter Facility, 8 December 2008.

[46] Trapp; Linda Herridge. "New shoes put pep in crawlers' step." *Spaceport News* (43, 21), 22 October 2004: 1 and 7.

[47] ASME; NASA KSC, *Crawler Transporters.*

[48] United Space Alliance (USA). *Crawler Transporter: General.* PowerPoint presentation, 14 January 2008, 6.

inspects the truck assemblies. Also while inoperative, the Crawler frames are cleaned of old grease and fresh grease is applied.[49]

With the Space Shuttle Program, the Crawler is first put to use when the Space Shuttle vehicle is ready for stacking procedures. The Crawler leaves its parking site, and using the special "Crawlerway," is driven to the MLP's parking site, where it is maneuvered into place underneath the platform.[50] Once in position, the Crawler's chassis is lifted to the point of contact with the MLP. The MLP is attached to the Crawler at four places, and is then released from its six support pedestals. The Crawler lifts the platform and carries it to the east side of the VAB, where it enters either High Bay 1 or 3. The MLP is lowered and mated to six support pedestals within the bay, and the platform is then detached from the Crawler, which lowers completely to exit the VAB. The transporter usually remains positioned on the Crawlerway to the east of the VAB until the Shuttle is completely stacked.[51]

Once the Space Shuttle vehicle is cleared to go to the launch pad, the Crawler returns to the High Bay, and the same mating procedure described above is performed. Each Crawler has the capability of lifting, transporting, and lowering the Space Shuttle vehicle and/or MLP without the aid of auxiliary equipment, and to supply limited electrical power to the platform during transit. Then, using its laser guidance and leveling system, the transporter carries the Shuttle and MLP combination along the Crawlerway to either LC 39A (3.5 miles) or LC 39B (5 miles), at a speed of one mile per hour, requiring 160 gallons of fuel per mile.[52] With the leveling system, the Crawler is able to keep the Shuttle within one foot of vertical during the approximate six hour trip from the VAB to the launch complex. Inside the launch complex gate, the Crawler is slowed to approximately one-third of a mile per hour to travel up the 0.25 mile, five degree inclining ramp to the launch pad.[53]

A fully-loaded Crawler Transporter requires a crew of twenty to thirty persons to operate. One is the certified test conductor, who oversees the entire move from one of the Operator's cabs. Four people are transporter drivers, who are arranged two per operator's cab. The two drivers in each cab rotate about every hour and operate the vehicle in a standing position. There is a wheel for

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[49] Trapp; "Bridge Painter." *Dirty Jobs with Mike Rowe*. (Silver Spring, Discovery Channel, 7 August 2007).
[50] The Crawlerway extends from the VAB to each launch pad and has various short branching trackways to the Crawler servicing and parking area and the MLP servicing and parking area. The Crawlerway has a total width of 130 feet, which contains two 40-foot-wide trackways separated by a 50-foot-wide grass median. Each trackway consists of four layers of differing materials, with a combined depth of 8 feet. The top layer consists of river gravel; the second layer is graded crushed stone; the third layer is select fill; and the fourth layer consists of compact fill. NASA. *Facts*, 31.
[51] NASA KSC, *Crawler Transporters;* NASA KSC, *KSC Transporters.*
[52] Unloaded, the Crawler can travel up to two miles per hour. NASA KSC, *Crawler Transporters;* NASA KSC, *KSC Transporters.*
[53] Although the driving time typically amounts to six hours, the entire process can take twelve to fourteen hours. Linda Herridge. "Crawler group keeps shuttle rolling along." *Spaceport News* (48, 10) 30 May 2008, 8.

steering the Crawler, a knob that controls the speed of the vehicle (up to one mile per hour when loaded), and a brake pedal. Even at one mile per hour, it takes twenty feet for the Crawler to come to a complete stop. In the control room, there are various engineers and technicians to monitor the engines and systems. The remainder of the crew walks around outside of the Crawler, including underneath it, to listen for any unusual sounds. They also aid the drivers, who cannot see to the opposite side of the Crawler, or behind them.[54]

At the pad, the Shuttle and platform combination is lowered and attached to six support pedestals. The Crawler's laser docking system allows the vehicle to dock within 0.5 to 0.25 inches of the fixed "dead zero" position. Once this is complete, the Crawler is driven to the outside of the launch complex's perimeter fence, where it waits to carry the MLP back to its parking site after the Shuttle is launched. When the MLP is returned, the Crawler then returns to its own parking and maintenance site.[55]

The Crawler Transporters were listed in the National Register of Historic Places on January 21, 2000. They were nominated under cover of the Multiple Property Listing, *Historic Cultural Resources of the John F. Kennedy Space Center, Florida* for its exceptional national importance within the context of the Apollo Space Program, 1961 through 1975. The original Multiple Property submission was prepared between 1997 and 1998, and signed by the Florida State Historic Preservation Officer in August 1998. The Multiple Property Documentation Form and Crawler Transporter nomination were revised in 2007 to include the Space Shuttle Context, ca. 1969 – 2010.[56] The Crawlers are eligible under Criterion A in the areas of Transportation and Space Exploration and under Criterion C in the area of Engineering. Because they have achieved exceptional significance within the past 50 years, Criteria Consideration G applies.

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[54] Herridge, "Crawler group," 8; NASA KSC, *Crawler Transporters;* NASA KSC, *KSC Story, 30;* NASA KSC, *KSC Transporters.*
[55] ASME; *Crawler Transporters*; *KSC Transporters*; Trapp.
[56] Trish Slovinac and Joan Deming. National Register of Historic Places Multiple Property Documentation Form, *Historic Cultural Resources of the John F. Kennedy Space Center, Florida.* October 2007

Physical Description[57]

Once depicted as "a huge square platform supported at each corner by a military tank," the Crawler has overall dimensions of 137' in length and 114' in width; its height ranges from 20' to 26'. The vehicle is comprised of a steel chassis and four steel truck assemblies. For ease of reference, the sides of the Crawler are numbered 1 through 4 (Figure No. A-10). "Side 1" and "Side 3" are the shorter sides of the transporter and correspond to the top and bottom of the Space Shuttle vehicle, respectively, when being moved by the Crawler.[58] "Side 2" and "Side 4" are the longer sides and correlate to the port and starboard sides of the shuttle, respectively.[59] Similarly, the four truck assembly connectors are referred to as Corner A, Corner B, Corner C, and Corner D (Figure No. A-10). Corner A is at the Side 1 end of Side 4; Corner D is at the Side 3 end of Side 4. On Side 2, Corner B is at the Side 1 end and Corner C is at the Side 3 end.

The chassis is a rigid steel framework with overall dimensions of 130' in length and 90' in width. Around the perimeter of the chassis is a 3'-wide walkway, which extends from the base of the chassis, and rises and lowers around the truck assemblies. The largest portion of the chassis is the rectangular core, which measures 129' in length, 53'-6" in width and 12'-6" in height. It is faced with aluminum and polystyrene foam panels, except for the first 18'-6" at Sides 1 and 3 on the top surface (Photo No. 10). Here, the truss-work remains open so that the center beam can be removed for access to the fuel tanks.[60] Side 1 (Photo Nos. 2, 3, and 9) and Side 3 (Photo Nos. 5-7) of this rectangle are each defined by a six-panel flat Pratt truss. Four of the panels are open; two are backed by water cooling radiators. On each side, there are two exhaust pipes within the left half of the truss, and one in the right half.[61] The only variance between the two sides lies with the metal steps. On Side 1, the steps ascend perpendicular to the chassis to provide access to the MLP. Those on Side 3 rise parallel to the chassis and are used to access the top of the Crawler when no load is present.

Side 2 (Photo Nos. 3-5) and Side 4 (Photo Nos. 7-9) of the rectangular core are each defined by a four-panel flat Pratt truss in the center; the inner two panels are backed with

[57] The two Crawlers, Crawler Transporter 1 and Crawler Transporter 2, are identical in layout and systems. Since Crawler Transporter 1 was the photographic model, it is that vehicle that is described herein, with any differences noted as applicable.
[58] Sides 1 and 3 interchangeably serve as the front or back of the transporter, depending on the direction of travel. When the Crawler is carrying the MLP/Space Shuttle combination to the launch pad, Side 3 is the front of the vehicle. On the return trip, Side 1 serves as the front of the transporter. These numeric designations also correspond to those given to the four sides of the MLP, i.e. the Crawler is positioned under the MLP so that Side 1 of the Crawler is directly under Side 1 of the MLP.
[59] The official names of the sides of each Crawler Transporter, as designated by NASA, are "Side 1," "Side 2," "Side 3," and "Side 4;" therefore, these are the titles used throughout the description.
[60] There is one fuel tank on each end of the Crawler. As for the structure, all of the remaining steel members are welded, which provides additional strength. Planning Research Corporation, Cocoa Beach. "Crawler Transporter System Description & Theory of Operation." February 1980, 14.
[61] These were added to the vehicle ca. 2003, see page 15.

aluminum/polystyrene foam panels. At the center of the truss is a metal stair case that lowers towards the left, providing access to the Crawler from the ground. At each end of Sides 2 and 4 are the connectors which attach the truck assemblies to the chassis. The connectors are essentially a large triangular truss, with the 38'-long hypotenuse against the rectangular core. At the projecting end is a small rectangular piece that contains a connector plate for the MLP on the upper face (Photo No. 12) and a 48"-diameter guide tube on the underside. This tube is welded to the chassis and is used to connect it to the truck assembly.

Attached to the truck assembly connectors at Corners B and D are the Operator's Control Cab No. 1 and No. 3, respectively (Photo Nos. 3 and 7). Each cab has overall dimensions of 8'-8" in length, 6'-10" in width, and 7'-9" in height. Extending from the base of the truss connector is the 3'-wide walkway to the cab door. The front side of the cab is a window-wall; the other two sides have windows in the upper two-thirds of their surface; and the back wall contains the entry door. Inside the cab, there are two chairs, one near the center and one within the back outer corner. All of the control panels are located along the front side of the cab across a "U"-shaped panel (Photo No. 11).

Chassis Interior

Within the chassis are the mechanical and electrical equipment, as well as the main control room and a communications room. The main control room is centered along Side 2 and has overall dimensions of 26' in length and 18' in width (Photo No. 36). It is essentially rectangular in plan, with chamfered inner corners and square cut-outs at the outer corners. Within each outer cut-out is a door into the room. Along the right wall (towards Side 1), the right chamfer, and the right half of the front wall (towards Side 4) are control consoles (Photo No. 24). There is an original electrical cabinet (Photo No. 25) on the left wall (towards Side 3), and a new electrical cabinet along the left chamfer. Additionally, in the center of the room are two new electrical panels. At Corner D is the small, dual-level communications room (Photo No. 26). Both levels contain interface panels for the communications system.

The remainder of the interior of the chassis contains the Crawler's motorized equipment (Photo No. 34).[62] Within each Zone 1 and Zone 5 sits one of the Crawler's two direct current (DC) engine generator sets (Photo Nos. 17 and 18). Each generator set consists of one 2750 horsepower (hp) engine that runs four 1000 kilowatt (kW) generators, each of which operates four of the 375 hp propel motors within the truck assemblies. Within each Zone 2 and Zone 4 is one of the Crawler's two alternating current (AC) engine generator sets (Photo Nos. 19 and 20). Each AC generator set, which runs all of the onboard systems, such as the hydraulic subsystem and the lighting and ventilating equipment, consists of one 1065 hp diesel engine that operates

[62] For ease of reference, this text will utilize the Crawler Transporter Group's internal fire zone divisions when discussing the placement of a particular piece of equipment. There are five equal-sized fire zones, which are numbered 1 through 5 beginning at the Side 1 end of the chassis. USA, 20.

two 750 kW generators. There are also two auxiliary AC subsystems, each composed of one 335 hp diesel engines and two 150kW generators.[63]

Within the chassis interior, along Side 4, are four different "skids" for three systems.[64] Along the wall, mainly in Zone 3, but continuing into Zones 2 and 4, are the main and redundant power pack skids for the JEL hydraulics system (Photo No. 21). Each of the JEL power packs contains two double-ended, 150-horsepower electric motors that operate two variable displacement pumps, providing hydraulic pressure to the JEL cylinders on each truck assembly. To the inner side of the JEL skids, solely within Zone 3, is the main and redundant power pack skid for the steering hydraulics system (Photo No. 22). Like the JEL power packs, each of the steering power packs contains two double-ended, 150-horsepower electric motors that operate two variable displacement pumps, providing hydraulic pressure to the steering cylinders on each truck assembly. Finally, to the inner side of the Zone 2 AC generator set sits the main and redundant power pack skid for the supercharger system and the cooling system (Photo No. 23). Each of the supercharger power packs consists of one double-ended, 20-horsepower motor that operates two variable displacement pumps, which provide hydraulic fluid to the JEL and steering systems. The cooling power pack has one 15-horsepower motor to drive a fixed displacement pump, which provides fluid to the JEL and steering pumps to limit their temperature.[65]

Truck Assembly

Each truck assembly measures approximately 44' in length, 24' in width, and 12' in height, and is comprised of two tread belts (tracks), four propel motors, four brakes, four vertical JEL hydraulic cylinders, three steering arms, and four horizontal steering hydraulic cylinders (Photo Nos. 13 and 14). The tracks are on the outer side of each truck assembly and are parallel with the long sides of the chassis. Each track contains fifty-seven shoes that are connected to one another and the frame with four different types of pins.[66] Each shoe is individually cast, weighs roughly one ton, and has dimensions of 7'-6" in length and 1'-6" in width (Photo No. 15). The tracks are propelled by four horizontal mill-type electric motors, each rated at 375 horsepower. These four motors are arranged in pairs, with one pair at each end of the truck assembly (Photo No. 14). Each motor has its own brake assembly, which is located directly beneath it.

In the center of the truck assembly is the ball bushing assembly for the guide tube, which connects it to the chassis. This guide tube also "keeps the crawler truck in alignment, absorbs horizontal thrust from propelling and steering, provides a pivot for the crawler truck, and permits

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[63] NASA KSC, Crawler Transporters; PRC, 29-30; Trapp; USA, 9-10.
[64] "Skid" refers to the small platform on which the components are mounted; Trapp.
[65] PRC, 30-31; USA, 12-13.
[66] The shoes are "connected with hardened steel belt pins secured by T-head pins which are in turn secured by cotter pins and welded-on-steel retainer pins." PRC, 19.

vertical movement of the chassis in relation to the crawler truck."[67] The guide tube is protected by a dust shield, which is attached to the base of the tube, which sits on top of the truck assembly (see Photo No. 13). Directly adjacent to the front and back of the guide tube are two 20"-diameter JEL cylinders (Photo Nos. 13 and 16).[68] These cylinders perform three different functions. The semiautomatic jacking functions raises and lowers the Crawler's chassis and its MLP/Shuttle load.[69] The automatic leveling system keeps the diagonally opposite corners of the chassis level, while the automatic equalization system provides an equal load distribution across the diagonally opposite corners. These systems are what allow the Crawler to keep the Space Shuttle Vehicle vertical, even during the incline at the launch pad.[70]

To the front and rear of the guide tube and JEL cylinder grouping is an outboard steering arm; the inboard steering arm projects out from the inner track frame (Photo No. 14). Assembled horizontally between each outboard motor and the inboard motor are an outboard steering cylinder and an inboard steering cylinder. These seven components combine to form the Crawler's steering system. The vehicle can be operated in three different modes: the "Great Circle Mode," the "Crab Mode," and the "Independent Mode." In the first mode, the trucks at each end of the vehicle are turned in opposite directions to allow the Crawler to negotiate curves in the Crawlerway. In the second mode, all four trucks are turned in the same direction, enabling the transporter to move diagonally. The last mode allows the operator in each cab to control the trucks and his end separately. This allows the Crawler to move through confined areas.[71]

[67] PRC, 19.
[68] The "front and back" are considered the short ends of the truck assembly.
[69] This action is what causes the height of the Crawler to range from 20' to 26'. See page 18.
[70] See page 16. If the differential pressure between the opposite corners exceeds 250 pounds per square inch, the system will shut down, and the Crawler will become inoperable. NASA KSC. *Apollo/Saturn V MILA Facilities Descriptions* (KSC) 30 June 1965, 1-42 and 1-43; PRC, 29; USA, 17.
[71] USA, 18.

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Figure A-1. Aerial showing initial layout of Crawler Transporter 1 components at KSC, May 11, 1964.
Source: John F. Kennedy Space Center, KSC-64C-3716, accessed via NASA Image Exchange (NIX) at http://nix.nasa.gov/.

Figure A-2. Construction of Crawler Transporter 1 at KSC, November 9, 1964.
Source: John F. Kennedy Space Center, KSC-64C-5542, accessed via
http://mediaarchive.ksc.nasa.gov/search.cfm..

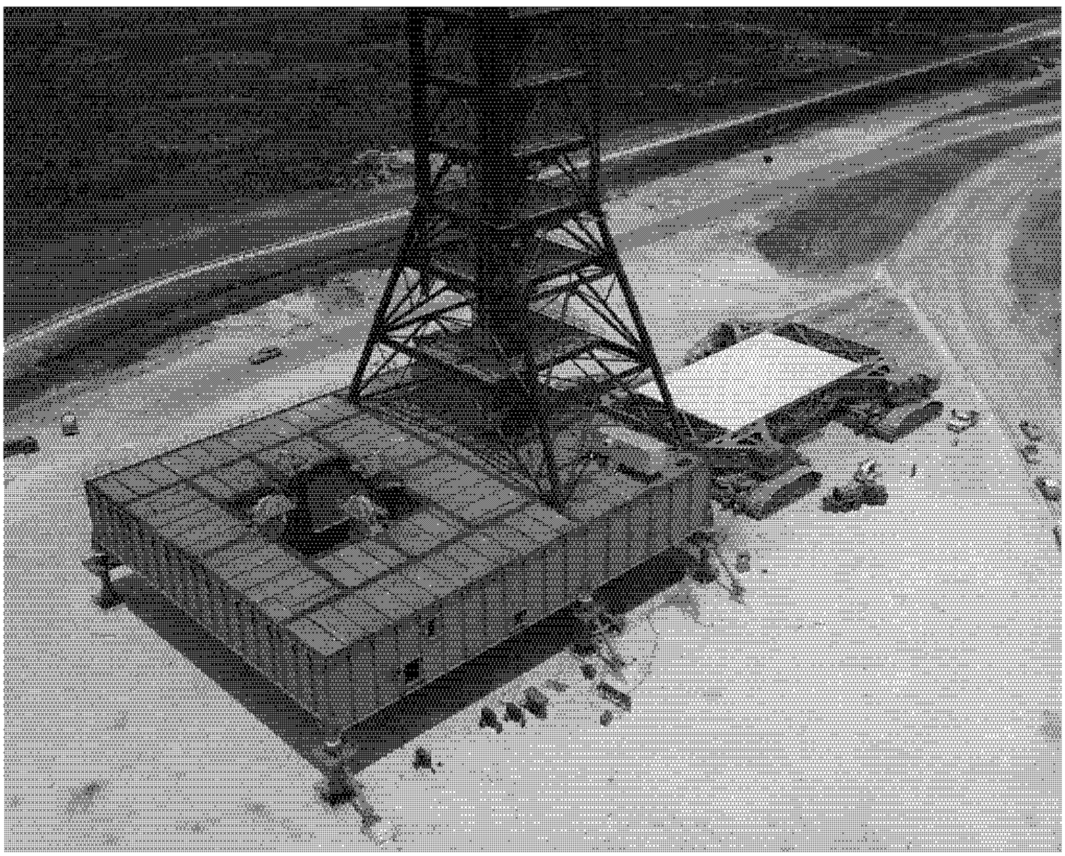

Figure A-3. Crawler Transporter 1 moving underneath Mobile Launcher 3, May 20, 1965.
Source: John F. Kennedy Space Center, KSC-65C-3331, accessed via NIX at
http://nix.nasa.gov/.

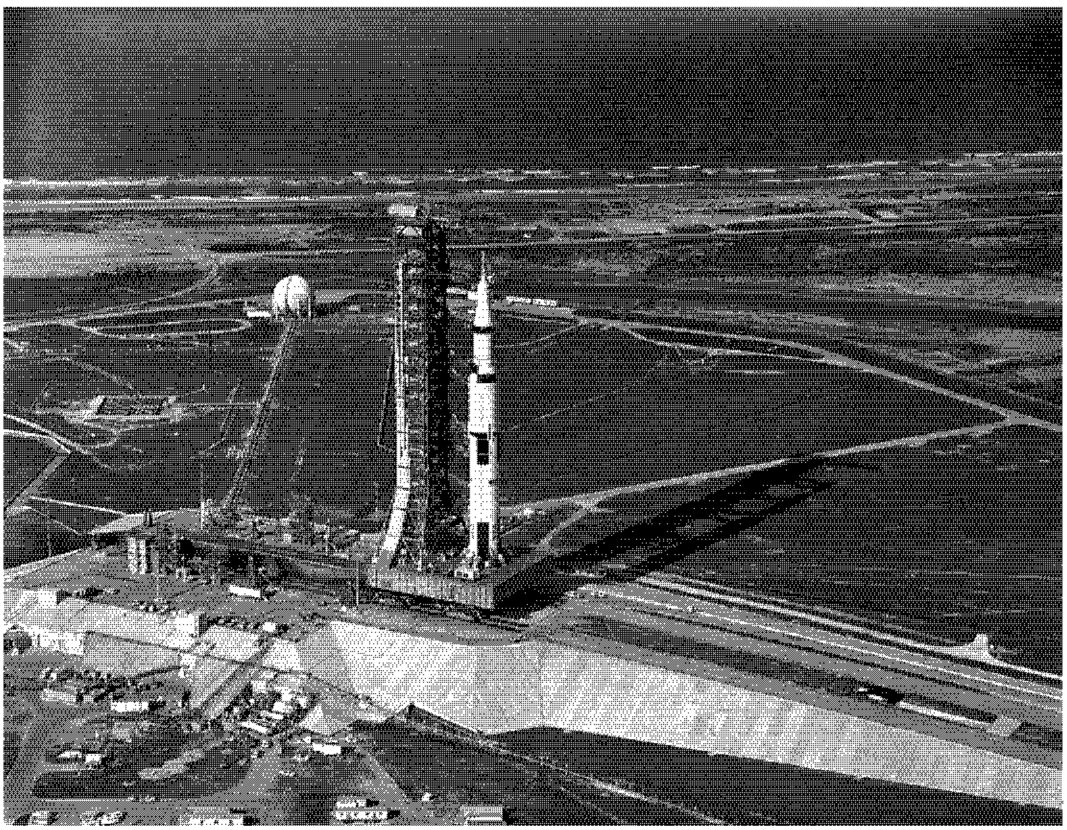

Figure A-4. Apollo 11 approaching Launch Pad 39A atop Crawler, May 20, 1969.
Source: NASA Headquarters, GPN-2000-001850, accessed via NIX at http://nix.nasa.gov/.

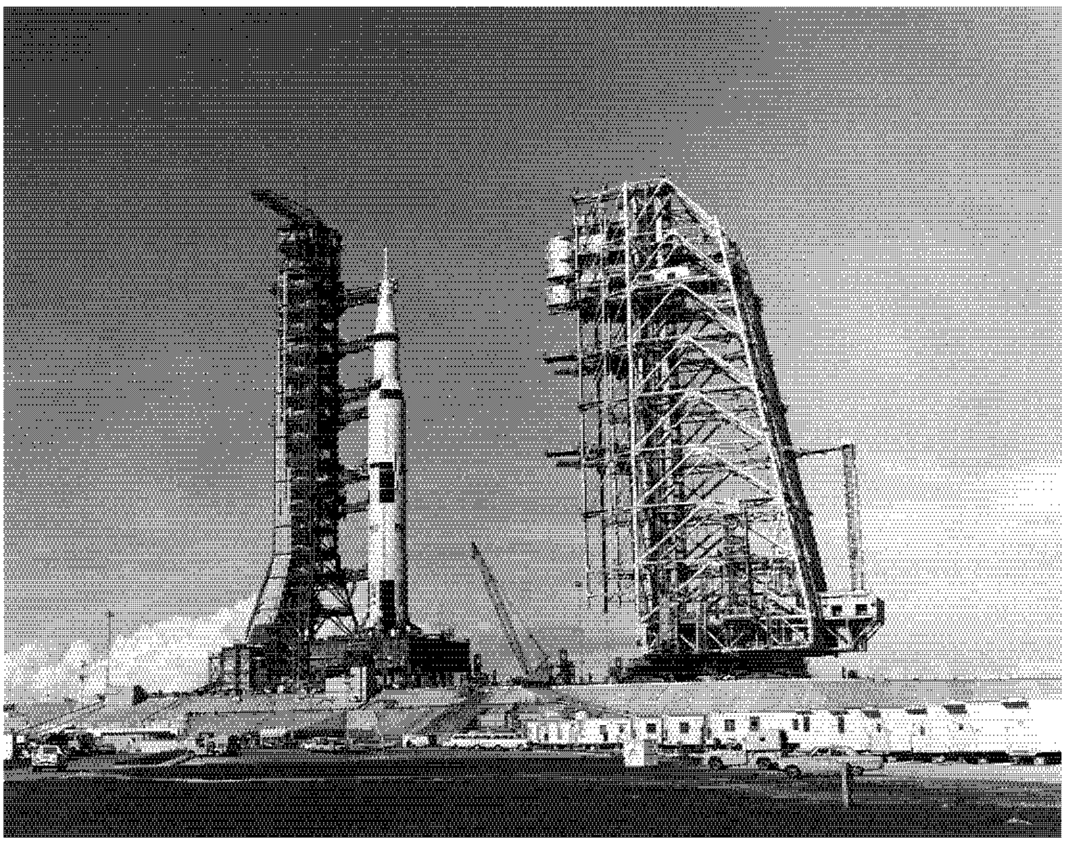

Figure A-5. Mobile Service Structure (right) being carried away from Apollo 11/Launch Pad 39A by Crawler, July 1, 1969.
Source: John F. Kennedy Space Center, KSC-69P-0569, accessed via NIX at http://nix.nasa.gov/.

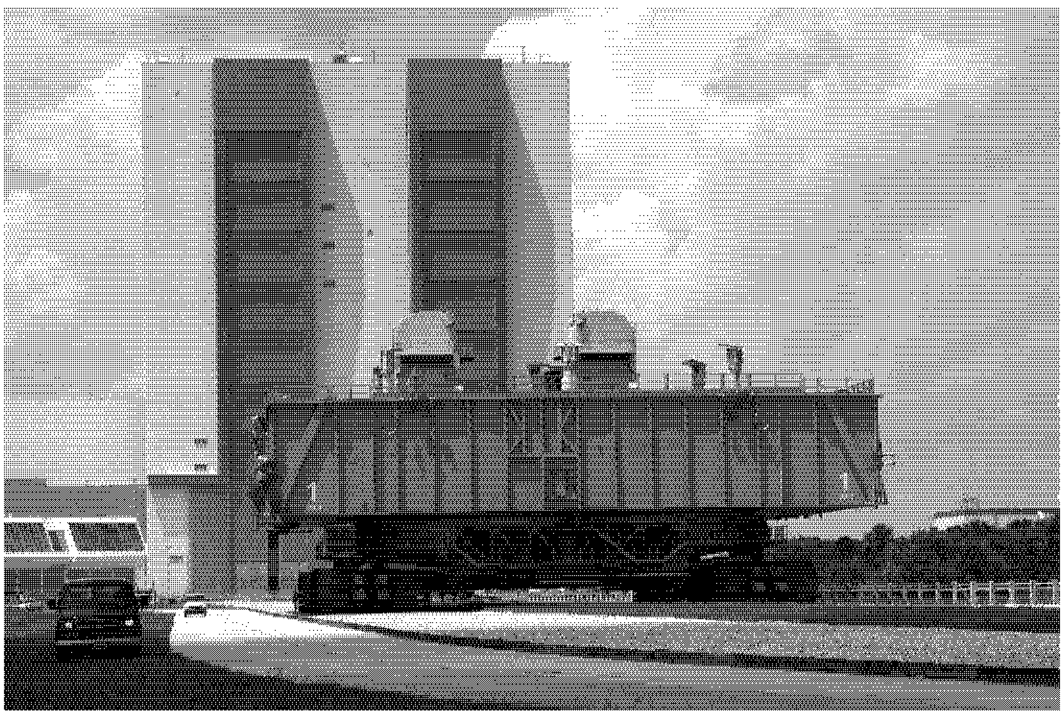

Figure A-6. Crawler Transporter moving a Mobile Launcher Platform, August 18, 2003.
Source: John F. Kennedy Space Center Archives, KSC-03PD-2357, accessed via NIX at http://nix.nasa.gov/.

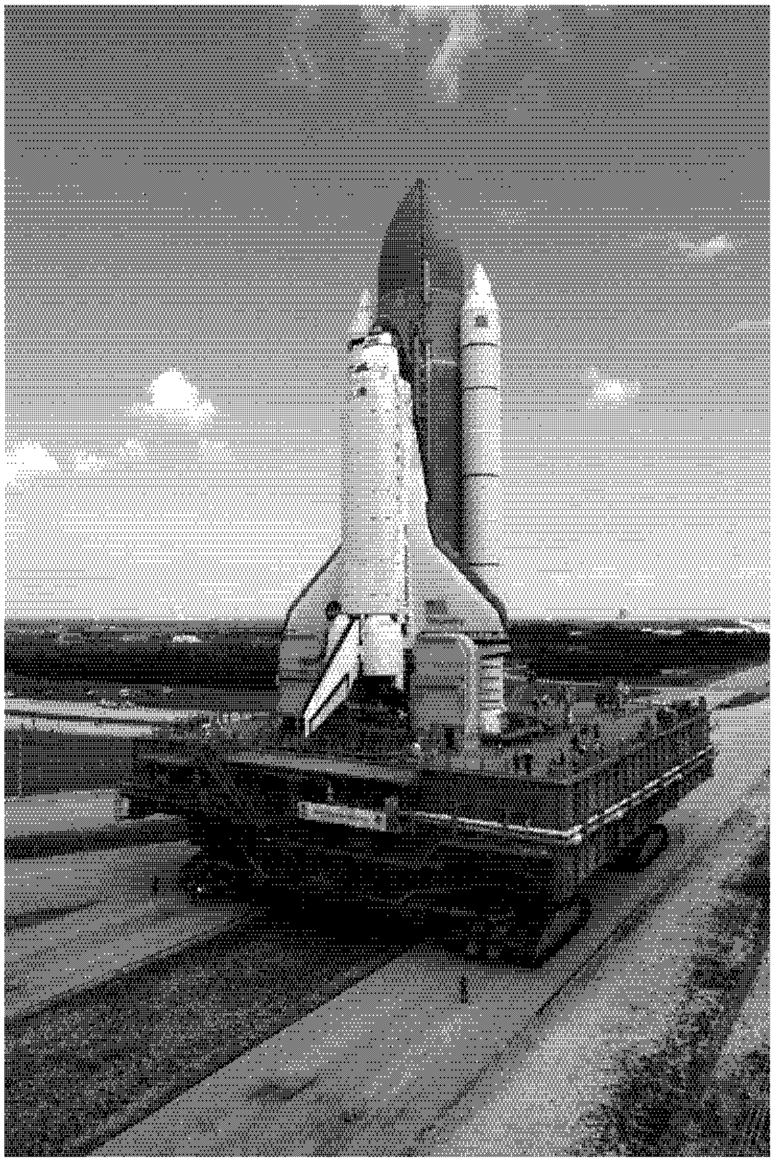

Figure A-7. Crawler Transporter carrying Space Shuttle Discovery to Launch Pad 39B, April 6, 2005.
Source: John F. Kennedy Space Center, KSC-05PD-0600, accessed via NIX at http://nix.nasa.gov/.

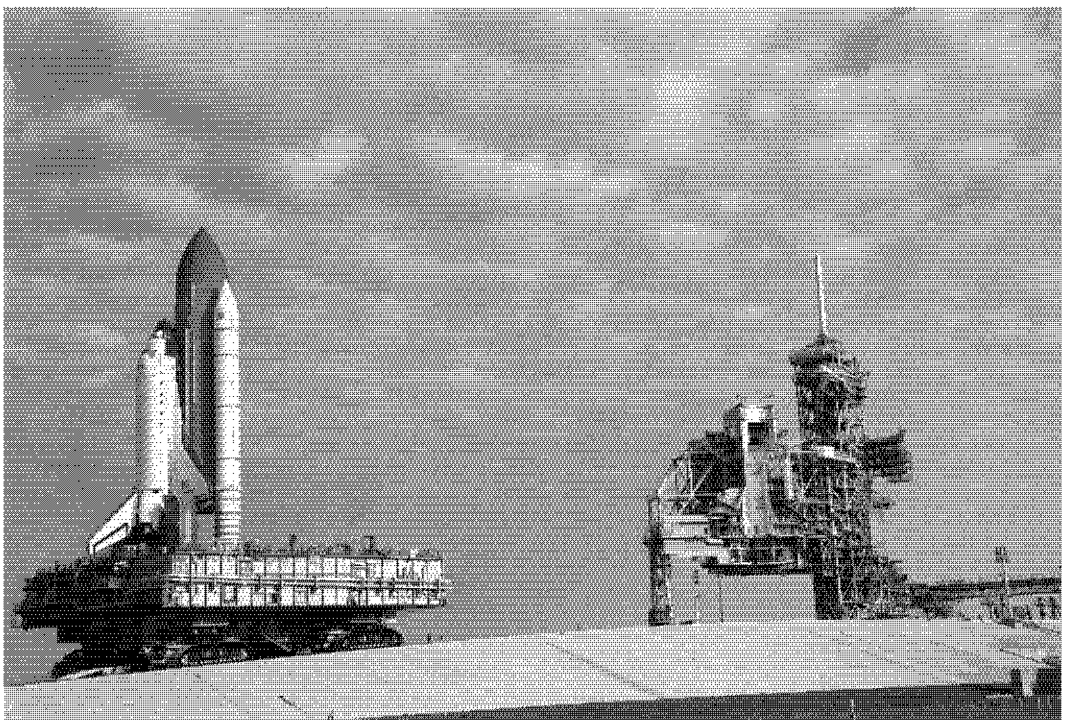

Figure A-8. Crawler Transporter carrying Space Shuttle Discovery up the five percent incline at Launch Pad 39B, May 20, 1999.
Source: John F. Kennedy Space Center, KSC-99PP-0565, accessed via NIX at http://nix.nasa.gov/.

Figure A-9. Workers preparing to remove a broken shoe from a Crawler, October 31, 2000.
Source: John F. Kennedy Space Center, KSC-00PP-1632, accessed via NIX at http://nix.nasa.gov/.

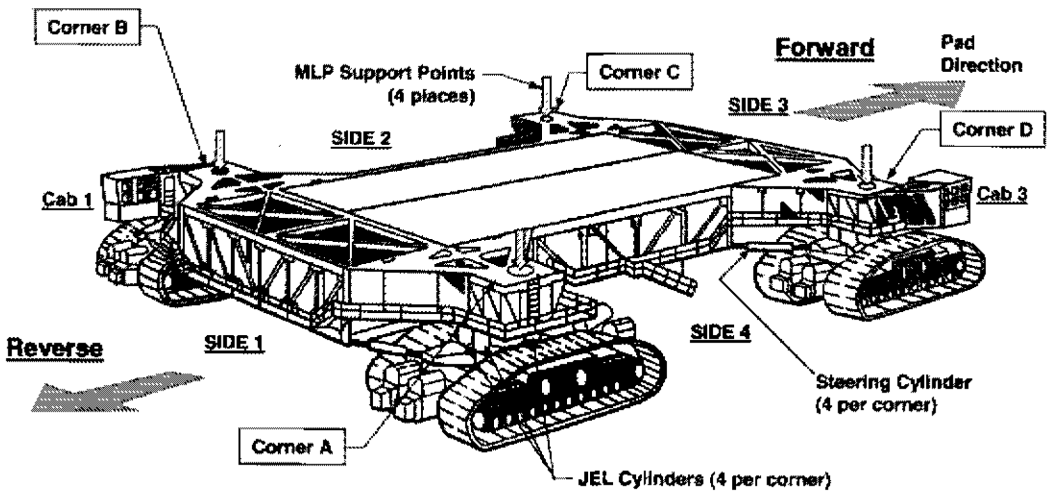

Figure A-10. Diagram of the Crawler Transporter, January 14, 2008.
Source: United Space Alliance. *Crawler Transporter: General.* PowerPoint presentation, January 14, 2008.